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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM 117

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AERIAL NAVIGATION BY DEAD RECKONING.

By Pierre Maffert.

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AERIAL NAVIGATION BY DEAD RECKONING.*

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The problem to be solved, as presented to the pilot or observer of an aircraft, is as follows: The aircraft starting from A must land at B, the only data being the speed of the airplane, the altitude (which can be estimated with sufficient accuracy) and the orientation D of the course (Fig. 1).

The above data would be amply sufficient, were it not for the fact that the airplane is constantly subjected to a wind of variable direction and strength. Since winds exert considerable influence, both on the speed and direction of an aircraft, the problem consists in determining the magnitude of the variations due to these aerial currents and in deducing from them the new orientation to be adopted in order to arrive at the point B.

If the speed and direction of the wind were known, nothing would be simpler than to determine this new course. The following description of the method to be employed in this event is borrowed from Mr. Le Prieur.

Let O (Fig. 1) be the center of a circle whose radius represents the direction and speed of the aircraft. Let OW represent the direction and velocity of the prevailing wind on the same scale. Let $O\Delta$ be the direction in which it is desired to travel with reference to the earth. Draw a straight line through W parallel to $O\Delta$, cutting the circumference of the circle at x.

* From "Premier Congrès International de la Navigation Aérienne," Paris, November, 1921, Vol. II, pp. 73-78.

The direction XO is the compass bearing which must be maintained by the aircraft in following the course OΔ. The resultant of XO (= V) and OW is XW, which is parallel to OΔ, having been made so by construction. Thus, when the direction and velocity of the wind are known, there is nothing simpler than to deduce from them the course to hold by the compass, as also the speed with reference to the earth (XW), thereby rendering it possible to regulate its time schedule exactly.

The resultant speed, if a course were held equal to the orientation of the itinerary, would be given in direction and magnitude by the diagonal OY of the parallelogram constructed with the speed of the aircraft OV and the velocity of the wind OW. This fact is of comparatively little interest to the pilot, but it can be extremely useful in determining the direction and velocity of the wind, which, unfortunately, are also among the unknown quantities.

The method given here differs from the one employed by Le Prieur, in that the latter, in determining the unknown quantities, is based on the mean drift, while my method is based on the resultant speed and the mean drift. I obtain, moreover, the mean drift by an entirely different method. This method presents fewer chances for error and simplifies the matter of the sightings (there being only two on a single point). Furthermore, by means of a special corrector, I obtain all the useful data by entirely mechanical means, thus reducing the work of the observer and the duration of the operation to a minimum.

In short, the problem is to determine the course to be held by the compass and the speed with reference to the ground for this course, knowing the speed OV of the airplane, its altitude and the orientation of its itinerary.

<u>Known</u>.

OV in direction and magnitude,

H altitude of aircraft.

<u>Unknown</u>.

OW in direction and magnitude,

XW in direction and magnitude,

OX in direction and magnitude,

XO in direction.

As previously mentioned, the solution of the problem depends upon the knowledge of wind OW in direction and magnitude. In order to find this, we must first find OY.

DETERMINATION OF MEAN DRIFT AND RESULTANT SPEED.

(Angle of route not corrected.)

By definition, the <u>drift</u> is the difference between the angle of route and the course to be followed by the compass.

The <u>resultant speed</u> is the speed of an aircraft with reference to the ground.

Like Le Prieur's instrument, the one we are about to describe consists essentially of a sight and a corrector.

The sight may be either a simple sighting line, with front and rear sight, or a collimator.

The axis xy of this sight, in its initial position, is horizontal, parallel to the axis of the aircraft and pointed in the direction opposite to that of flight, if mounted behind the wings. It is pointed in the direction of flight, when mounted in front of the wings. It covers, in the former case, an angle of 180° toward the rear and in the latter case 180° toward the front (Fig. 2).

The corrector is the same for both directions, with only a slight difference in mounting. This arrangement was adopted, because the view is obstructed by the wings in one direction or the other. The rear position is more favorable for sighting.

This position of the sight is the base on which the following system is constructed. The sight is so constructed that it transmits to the corrector, which performs the operations and registers the results, the angular variations in both directions. Let β and α represent the respective angles formed by the line of sight with the vertical and horizontal planes passing through its initial axis.

We will now see how we can calculate OY in magnitude and direction. Let us suppose the sight mounted in the rear position, with its initial axis oriented in the direction of ΔO. With the aircraft at B, we will sight, at a time t, any point A, on the ground (Fig. 3).

B_1 is the vertical projection of B on the horizontal plane P, which includes the point A, and $x_1 y_1$ is the projection of xy on the same plane. Join A to B_1 and turn down the triangle B B_1 A with a right angle at B_1: or, after turning down (B) B_1 A.

In this triangle we know (B) B_1 = B B_1 = the altitude of the aircraft. We likewise know the angle at A = α, which is given by the sight. We can consequently calculate all the other unknowns of the triangle (B) B_1 A and especially the side b.

We now turn down the perpendicular at A on x_1y_1, thus obtaining the line AE and a new right triangle B_1 E A, of which we know one side b and one angle (the angle at B = β which is given by the sight). This triangle is therefore perfectly determined and its position in the plane P is likewise determined, since it has a right angle at E and since one apex is the stationary point A and one side (B_1 E) is a known segment of the line x_1y_1.

Let us now make another sighting toward A from the point C, the new position of the aircraft after the time t', the altitude of C being the same as the altitude of B.

For the demonstration, we will take C at any point in space. Let x'_1 y'_1 be the new position of x_1 y_1 in the plane P.

As we did for the point B, we can calculate C by means of the right triangle (C) C_1 A. By turning down the perpendicular at A on x'_1 y'_1 we obtain the line A E'.

By the same reasoning as the above, we can prove that the triangle C_1 A E'_1 is perfectly determined in all its elements, as well as its position in the plane P.

On examining Fig. 3, we note that the points $A\ B_1\ C_1$ are the apices of any triangle, of which we know two sides and an angle (the angle at A, which is a function of γ and of γ'). Hence this triangle is also perfectly determined. But what is $B_1\ C_1$? It is nothing but the projection on the plane B of the path actually traversed by the airplane in the time $t' - t$ (by construction in both magnitude and direction). The angle δ is therefore the drift sought.

It will now suffice to reduce the distance $B_1\ C_1$, in the time $t' - t$, to m/s and to construct the parallelogram of forces (Fig. 1), in order to obtain immediately the wind OW in both direction and magnitude. From this is deduced the corrected course XO and the ground speed XW.

It is easily seen that the above demonstration is valid for any position of the point A and that it likewise holds good for the forward orientation of the sight (Fig. 4).

There is one particular position of A, for which the operations are very simple. This is when A coincides with B_1. In fact, the triangle $B\ B_1\ A$ is reduced to a straight line, either $B\ B_1$ or $B\ A$ (Fig. 5).

In the triangle $(C)\ C_1\ A$ we find that the side c of the right angle coincides with $B_1\ C_1$. But, as we have seen, $B_1\ C_1$ is the projection, in the plane P, of the path actually traversed by the airplane. In this particular instance, therefore, we may call $c = B_1\ C_1$. This simplified process should be used, whenever possible, which is only in the rear position.

These various operations at first glance seem extremely long and complicated for an observer to make. In fact, they would be, if the observer had to make the calculations himself, one after the other, but, as I have already said, the operations are made automatically by a special corrector. The only work of the observer is to sight the point A twice and then to make a few simple motions, all mechanical.

In case of a flight over water the point A may be created artificially by means of small phosphorus floats.

DESCRIPTION OF CORRECTOR.

The whole apparatus consists of a sight provided with a chronograph and a correcting device. The latter consists of

1. A device synchronized with the sight and performing the operations mechanically;

2. An independent recording device giving XO and XW in the simplest manner. It transmits automatically the corrected angle of route to the pilot and records the results on paper ruled in square millimeters.

After having proclaimed the advantages of my method, it is only fair that I should mention its weak point, namely, the determination of the altitude. This difficulty is not experienced over level surfaces, either water or land. It may also be overcome, to a certain extent, in mountainous regions, by taking some summit of known altitude as the point A. I believe, however, that even under the most unfavorable conditions, by determining from a map the mean altitudes of the regions flown over, when it is impossible to select any point of exactly known altitude, the chances of error may be reduced to a small minimum and that the results will be sufficiently accurate.

I am convinced that this slight difficulty will be largely offset by the ease of manipulation of the small instrument, which gives in a few seconds all the data required for guiding an airplane toward its goal, in spite of the more often unfavorable conditions.

Translated by the National Advisory Committee for Aeronautics.

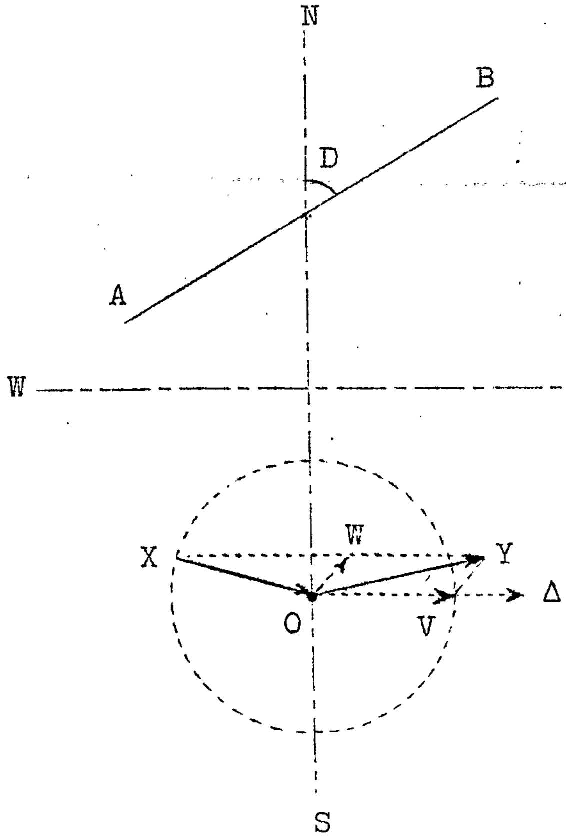

Fig. 1.

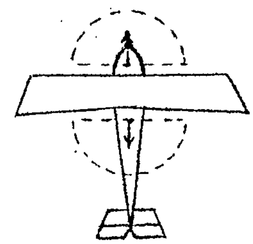

Fig. 2.

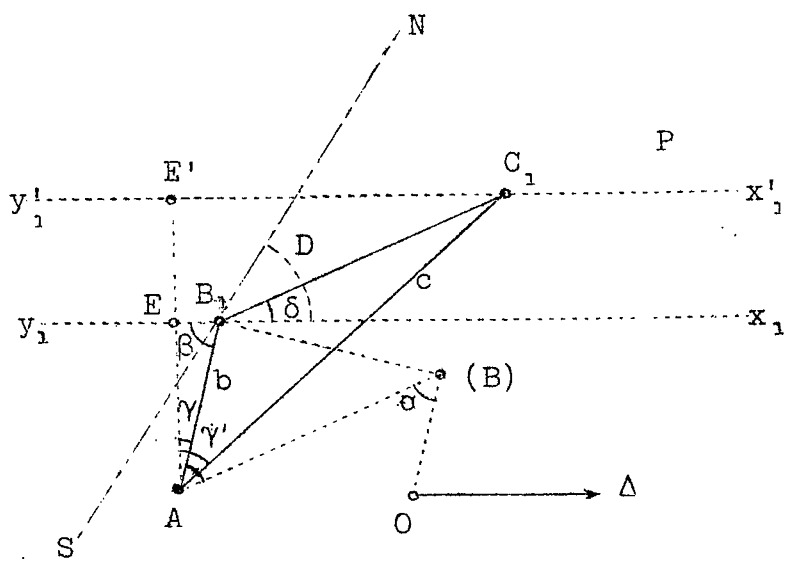

Fig. 3.

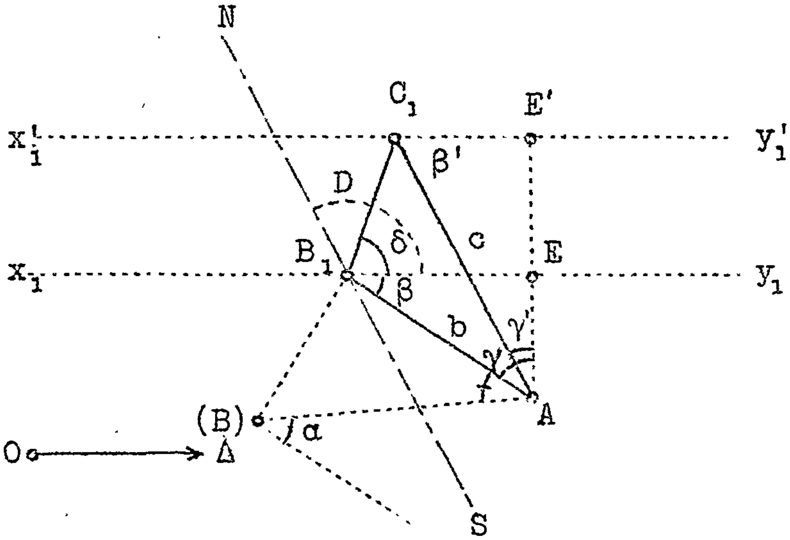
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Fig. 4.

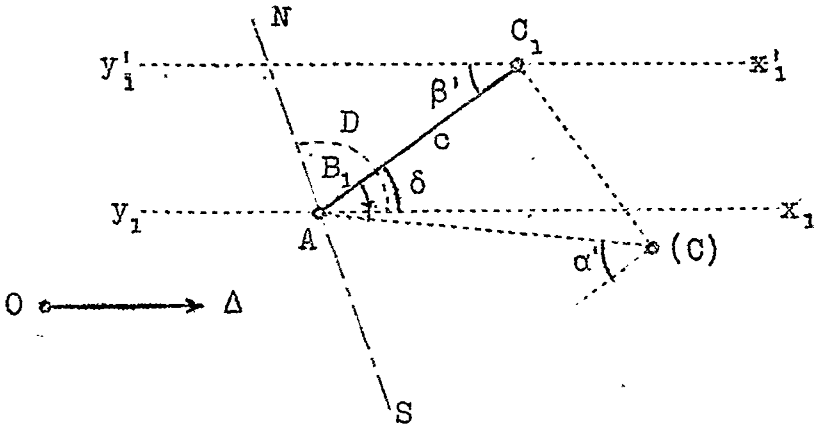
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Fig. 5.